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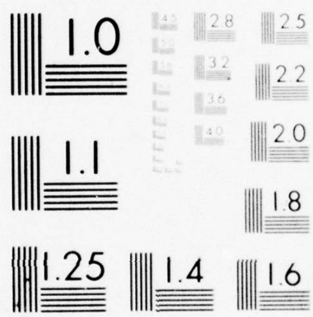

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USAARL REPORT NO. 77-11

COMPARISON OF OCULOMOTOR PERFORMANCE OF MONOCULAR AND BINOCULAR AVIATORS DURING VFR HELICOPTER FLIGHT

By

Mark A. Hofmann
Thomas L. Frezell

March 1977

Final Report

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U. S. ARMY AEROMEDICAL RESEARCH LABORATORY
Fort Rucker, Alabama 36362

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This investigation provides data concerning the visual performance of six binocular Army aviators and one monocular Army aviator during eleven flight maneuvers. All maneuvers were performed in a JUH-1H helicopter and visual data were acquired by means of a corneal reflection technique. Data were recorded on video tape and 16mm film. Thirteen visual areas were used to include: eight windscreen sectors; two side windows and chin bubbles; and an inside cockpit sector. Data presented include percentage of time spent in each sector, average dwell

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time per sector and sector transition (permutation) values. In addition to the objective data, a discussion of the retraining period for the monocular aviator is provided. The data revealed that, in general, both the monocular aviator and binocular aviators used the same visual sectors. However, the total percentage of time they spent in these sectors were often different and so were the dwell times. The most dramatic differences in visual performance appeared when aircraft movement was in the direction of the monocular aviator's visual deficiency and in terms of the time spent inside the cockpit. The monocular aviator was found to perform all maneuvers in a most acceptable manner.

SUMMARY

This investigation provides data concerning the visual performance of six binocular Army aviators and one monocular Army aviator during eleven flight maneuvers. All maneuvers were performed in a JUH-1H helicopter and visual data were acquired by means of a corneal reflection technique. Data were recorded on video tape and 16mm film. Thirteen visual areas were used to include: eight windscreen sectors; two side windows and chin bubbles; and an inside cockpit sector. Data presented include percentage of time spent in each sector, average dwell time per sector and sector transition (permutation) values. In addition to the objective data, a discussion of the retraining period for the monocular aviator is provided. The data revealed that, in general, both the monocular aviator and binocular aviators used the same visual sectors. However, the total percentage of time they spent in these sectors were often different and so were the dwell times. The most dramatic differences in visual performance appeared when aircraft movement was in the direction of the monocular aviator's visual deficiency and in terms of the time spent inside the cockpit. The monocular aviator was found to perform all maneuvers in a most acceptable manner.

Robert W. Bailey

ROBERT W. BAILEY
Colonel, MSC
Commanding

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INTRODUCTION

There is little question that helicopters have become an integral part of the U.S. Army's tactical structure. Also, there is little question that mission accomplishment and safe flight of the helicopter is dependent in large measure on external visual information received by aircrew personnel. Evidence that minimum adequate visual information is currently afforded Army aviators is substantiated by the very fact they can, and do, fly the machines. However, little is known with regard to what areas of the windscreen aviators most often use; how long they dwell in these areas; what dynamic response patterns they utilize to transition from area to area; where and what they view externally to the aircraft; or how these parameters change as a function of variables such as aircraft flown, maneuvers flown, level of training, or physiological state. Knowledge concerning these parameters is perhaps a first step in gaining information about what visual cues are used in helicopter flight control.

Though the visual sensory modality is considered almost without exception to be highly critical to helicopter flying, few research studies have been conducted measuring where the pilot looks during actual rotary wing flight. Two studies[1,2] were performed some years ago but were primarily concerned with establishing the minimum acceptable visual envelopes for aircraft. These studies examined visual performance, in various aircraft over a number of maneuvers, in terms of the frequency with which aviators utilized certain visual areas. While attempting to establish these visual envelopes, the investigators did study some visual performance of aviators while flying helicopters. It might be added that these particular studies appear to have been overlooked when one views the military standards concerning visual envelopes for helicopters. Since these studies, a number of new helicopters have been added to the Army inventory, the function and flight envelopes of helicopters have expanded, and the technology for recording visual performance has advanced providing more measures with greater accuracy.

More recently, two other studies[3,4] investigated a number of maneuvers gaining data by way of interview techniques as well as in-flight recording of visual performance for two aviators. The in-flight visual data were examined by using three lateral areas referenced to the windscreen and four vertical categories referenced to the earth's surface. The major emphasis of the in-flight visual performance, however, was directed at measuring performance during instrument flight rules (IFR) maneuvers. These efforts provided some needed information as to what instruments are used, how long they are used, and their order of usage.

With regard to visual meteorological conditions (VMC) rotary wing flight, several studies have just been conducted concerning visual performance.[5,6,7] Though information has been added to visual performance data, much yet remains to be established for this sensory modality which is so critical to safe flight.

In this regard, there may be merit in studying monocular visual performance during VMC helicopter flight. Perhaps the major binocular cue which a monocular aviator loses is that of retinal disparity. Though these cues may be useful to a distance of between 490-700 yards,[8] it does not appear necessary for the conduct of adequate flight control; a fact attested by a number of successful one-eyed helicopter pilots. However, there is little information available as to whether or not these monocular pilots tend to gain their flight control cues from the same areas which are visually "rich" for binocular aviators.

The purpose of this investigation was to gain data concerning visual performance during VMC while executing a number of maneuvers in a UH-1 helicopter. For purposes of comparison, data were acquired from one monocular aviator, after his return to flight status, and six binocular aviators.

METHOD

The binocular subjects were six Army aviators with a mean age of 29.4 years. Their flight experience ranged from 300 hours to 2500 hours with a mean of 1621 flight hours. The monocular aviator was a 34 year old male who is currently on flight status. His eye loss was the result of a facial injury incurred during hostile fire on a combat flight mission. These facial injuries resulted in enucleation of the left orbit in May of 1967. Prior to his injury he had flown a total of 652 hours of which 439 were combat mission hours. This injury was disqualifying for a Class II flight physical. This aviator (seeking a return to flight status) requested and received a medical evaluation in 1968. The medical evaluation did not recommend a return to flight status. This determination was based on a condition of recurrent subluxation of the right shoulder rather than the monocular condition. A Magruson-Stack procedure was performed on the right shoulder joint in February of 1969 and since that time there has been no history of dislocation. Again, in 1972, he requested another medical evaluation in an attempt to return to flight status. His case was evaluated by the Aeromedical Consultation Service located at Ft Rucker, Alabama. This evaluation was favorable medically and it was determined that the subject should undergo an upgraded evaluation flight (prior to his final graded evaluation flight) to determine if additional flight training would be

necessary because of the length of time since he had flown. The informal in-flight evaluation was performed on 12 April 1972 and administered by the Flight Standards Division. Several deficiencies were noted and are as follows:

a. At approximately 100 feet AGL "ballooning" was noted on normal approaches. The evaluee tended to fixate on the ground and would apply rearward cyclic pressure as the apparent ground speed suddenly increased.

b. Landings were consistently made to the right side of the runway.

c. Take offs were always accompanied by 20^{o} to 30^{o} of right yaw in climb out.

d. Hovering altitude tended to be somewhat higher than the desired three feet.

e. During autorotations, the evaluee tended to initiate his final pitch pull 10-15 feet higher than normal.

It was the opinion of the Standardization pilot that much of the evaluee's difficulty was due to his lack of recent flight experience (last flight was 21 May 1967) and difficulty in adjusting to obtaining flight control cues with one eye. It was felt that a period of "retraining" was necessary to develop the use of the visual cues and flight proficiency prior to a final evaluation flight. This additional flight training was provided in a UH-1H helicopter with a well qualified instructor pilot provided by the U.S. Army Aeromedical Research Laboratory at Fort Rucker, Alabama.

The retraining began on 18 April 1972 and lasted for two weeks. This training encompassed all standard helicopter maneuvers to include hovering turns, rearward flight, maximum performance take offs, confined area operations, slopes, pinnacles, and formation flight. Nonstandard and emergency maneuvers practiced were autorotations to include standard autorotations (both day and night), low level autorotations, and 180^{o} turn autorotations. Other flight maneuvers practiced were low level flight, nap-of-the-earth flight, and recovery from unusual attitudes. During this training, after-flight debriefings were conducted daily. These after-flight discussions were recorded and transcribed in chronological order.

Numerous variations were noted and discussed during this training period. Some of the areas of significance were:

a. It was pointed out by the instructor pilot (IP) that the monocular aviator tended to land the aircraft right of the center line with a

right yaw of 10^{0} to 15^{0}. When questioned about this the subject stated that he was aligned with the runway and that he was not in a right yaw position. The subject was instructed to exit the aircraft, walk away from it, and then look at its alignment. Returning to the cockpit he stated that it was clearly to the right of the center line with a right yaw. The aircraft was then aligned with the center line to give the subject another view. Subject stated that the aircraft appeared to be left of center and yawed left. Additional practice of this maneuver enabled this situation to be corrected. The subject stated he had shifted from referencing his body to an external referent to using fixed points on the aircraft and relating these to an external referent.

b. When instructed to maintain a stationary three-foot hover the pilot tended to randomly drift and gain altitude without his being aware of these deviations. The subject was asked what he was using for an external referent. He replied he would look at a tree line that was located approximately 100 meters from the aircraft. The subject was instructed to use cues closer to the aircraft (5 to 10 meters distance) as these objects would provide better visual cues for maintaining a precise hover. When the subject used cues which were closer, his performance rapidly improved. He had a slight tendency to fixate but quickly recognized this tendency led to over control and therefore started using a visual scan pattern.

This flight training aided the pilot in establishing new visual cues and gave him confidence that he could again fly with skill and precision while managing all of the in-flight ancillary tasks associated with flight. On 4 May 1972, the subject was administered his graded evaluation ride with a check pilot from the Department of Standards. All normal flight maneuvers were performed as well as nonstandard and emergency maneuvers. No evidence of visual difficulty presented itself during this evaluation. It was the opinion of the Department of Standards' check pilot that the subject was adequate in ability and proficiency for safe flight. A final evaluation check ride grade of 85 was given for the entire flight. On 18 August 1972, the Aeromedical Consultation Service recommended that the subject be returned to Class II flying duty subject to the following restrictions:

a. Flight with another aviator fully qualified in the aircraft flown.

b. Flight from the right seat (opposite his visual deficiency) to facilitate clearing the aircraft in turns.

c. Re-evaluation and testing at the Aeromedical Consultation Service annually and/or whenever transition to another type or series aircraft is contemplated.

d. Identification as a research subject to facilitate re-evaluation, gathering of information, and administrative handling of his case.

This recommendation was accepted and the individual was returned to flight status with the above mentioned restrictions.

APPARATUS AND PROCEDURES

Visual performance of all subjects was measured via a modified NAC Eye Mark recorder used in conjunction with either a video recording system (30 frames/sec) or 16mm motion picture camera (16 frames/sec). The NAC recorder utilizes corneal reflection and has a field-of-view of 60° in the horizontal and 43.5° in the vertical. The optically focused reticle which is reflected from the eye and superimposed on the image is approximately .5mm. Mounting modifications were required to assure accuracy during in-flight measurements. Figure 1 shows the aviator wearing the modified NAC recorder.

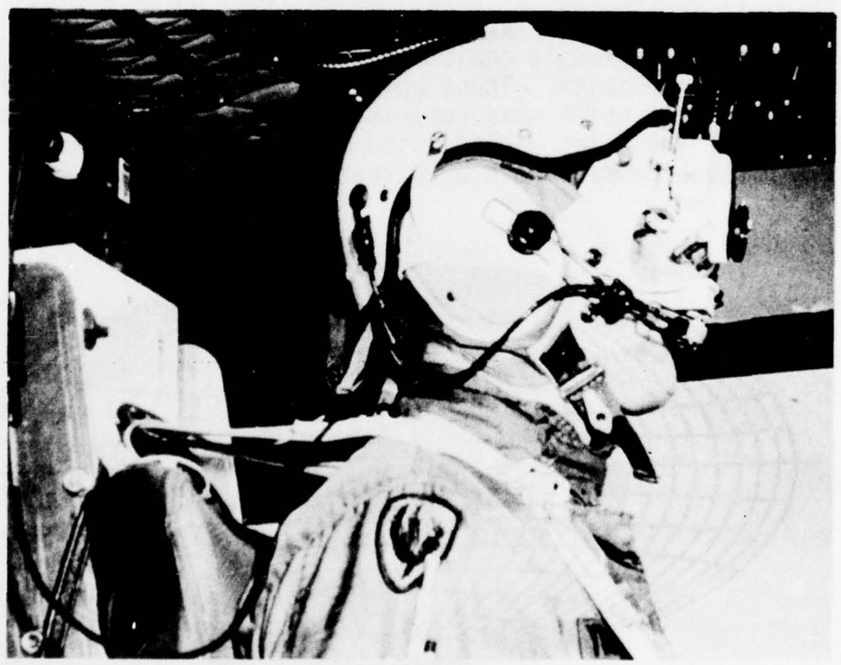


Figure 1. Subject Wearing Modified NAC Eye Mark Recorder

All recording was done in real time. For scoring purposes the aircraft visual areas were divided into thirteen sectors of interest. The sectors are as follows:

a. Eight (8) windscreen sectors - *Surface Area = 260 square inches each.

b. Two (2) chin bubble sectors - *Surface Area = 634 square inches each.

c. Two (2) side door sectors - *Surface Area = 560 square inches each.

d. One (1) inside cockpit sector.

*Note that sectors within each group are of equal surface area but not necessarily equal viewing area.

Figure 2 shows a visual plot of the viewing area of the UH-1H model helicopter. This plot, provided by the Bell Helicopter Company, Fort Worth, Texas, was generated using water line 64.05 and station 470.90. The black vertical and horizontal superimposed lines on this plot represent the divisions of the various windscreen sectors used in this investigation. A triangle depicts the area inclosing the visual center point for all subjects. These points were referenced to the right eye (the eye from which measurements were taken) and were determined on the ground after the pilot had adjusted the seat to his comfort and assumed a posture commensurate with that used in flight.

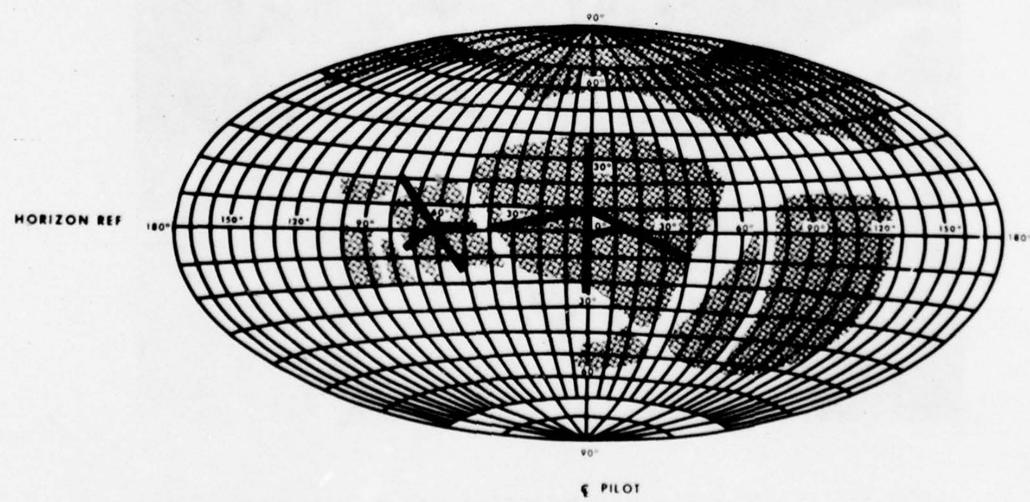


FIGURE 2. VISUAL PLOT, UH-1H

Each subject, prior to flying the helicopter, was fitted with the NAC recorder in the laboratory and checked for accuracy. He then proceeded to the aircraft for final hookup and additional calibrations. The subjects flew from the right seat (the pilot's normal position in a helicopter), adjusted to his own comfort. After each flight, each subject was again checked for accuracy to assure that the NAC recorder had not shifted.

Each subject performed a standardized set of eleven maneuvers common to helicopter operations. These were as follows:

a. Stabilized Hover.

b. Forward Hover.

c. Rearward Hover.

d. Hover Turn Left (90^{o}).

e. Hover Sidewards Left.

f. Hover Sidewards Right.

g. Hover Turn Left (360^{o}).

h. Hover Turn Right (360^{o}).

i. Hover Turn Right (90^{o}).

j. Normal Traffic Pattern - Take Off to Hover Terminate - Left Traffic.

k. Normal Traffic Pattern - Take Off to Touchdown - Right Traffic.

DATA ANALYSIS

After all data had been recorded, the tapes and/or film were brought back to the laboratory for scoring.[6] Time scoring was performed while playing the tapes back at one-half speed and consisted of recording the time spent in each sector. The timing system permitted accuracy to 50 msec. Time per sector for each maneuver for the six subjects was accomplished by pressing microswitches mounted on specifically designed boards to accommodate the fingers of each hand. Each board contained six switches with the thirteenth sector being represented by a foot switch. Each switch closure performed three functions. It provided a unique voltage to a digital voltmeter, caused a counter (time base) to stop and reset, and signaled the computer to accept both values. The voltage served to provide a unique core address for each sector and the computer was programed to add the incoming values to the appropriate

sector location. After all data were entered, the computer then performed the subsequent analysis required. All timing was forced, i.e., all flight time had to be accounted for by one of the sectors.

Perhaps the primary limiting factor of scoring time in this manner involves the reaction time of the scorers. However, the error introduced by this factor is considered minimal in that one can reasonably expect to record some time in any sector which was frequented by the eye for any period of time 100 msec or greater. This exists because, at the scoring speed, a 100 msec deviation appeared for 200 msec, which is within reaction time capability. The data supported this contention because scores were found in the 100 msec range. Measurement to this resolution can be considered adequate when one considers the response time in terms of ability to gain information. This scoring method will, of course, introduce some error when the eye mark is not visible to the scorer, since all time had to be accounted for by one of the sectors. When this event occurred, time was accumulated in sector one, or time spent inside. However, error introduced by this situation was considered negligible since the scorers did not often lose sight of the eye mark. Eye blinks theoretically could cause loss of the eye mark and result in time accumulated in sector one, but in most cases were not considered a problem inasmuch as they were below the scorer's response threshold. Eye blinks, as recorded during helicopter flight, have been reported to occur with average frequencies ranging from 18 to 24 per minute.[9] Duration of these blinks have ranged from under 20 msec to over 113 msec with 89% occuring below 56 msec.[10] With regard to saccadic movements influencing the data to any extent, this again, in the opinion of the authors, was minimal because saccadic movements for the visual angles involved would be of very short duration. Previous literature has stated that pilot head movements must be considered any time eye movement is greater than 15^{o} in any direction from the centrofoveal position.[1]

The sector transition measure consisted of a frequency count for transitions from one sector to another. Since there were 13 sectors, this yielded 156 permutations, e.g., sector one to sector three, sector three to sector one, sector one to sector five, sector five to sector eight, etc. As with the timing scores, the switch closures provided voltages that the computer manipulated so that each permutation was assigned a unique core address and a simple counter was set up to provide the frequency of occurrence. After all data were entered the computer then performed the subsequent analysis required. For this measurement score, reaction time was not critical in that frequency was all that was important, thus permitting the scorer to lag if necessary to record.

RESULTS AND DISCUSSION

The results of the 11 maneuvers will be presented and discussed individually with one figure and one table per maneuver. The data appearing at the left of the figures and tables pertain to the binocular group of aviators and the data appearing at the right of the figures and tables pertain to the monocular aviator. The figures represent the thirteen scored visual sectors. The aircraft windscreen was divided into eight visual sectors. The two side door windows and the two chin bubbles added four additional sectors. The inside area of the aircraft was the thirteenth sector. The numbers in the top right corner of each sector are for sector identification. The three values appearing in the sectors represent the following:

a. Total time spent in that sector in seconds.

b. Percent of total maneuver time spent in the sector.

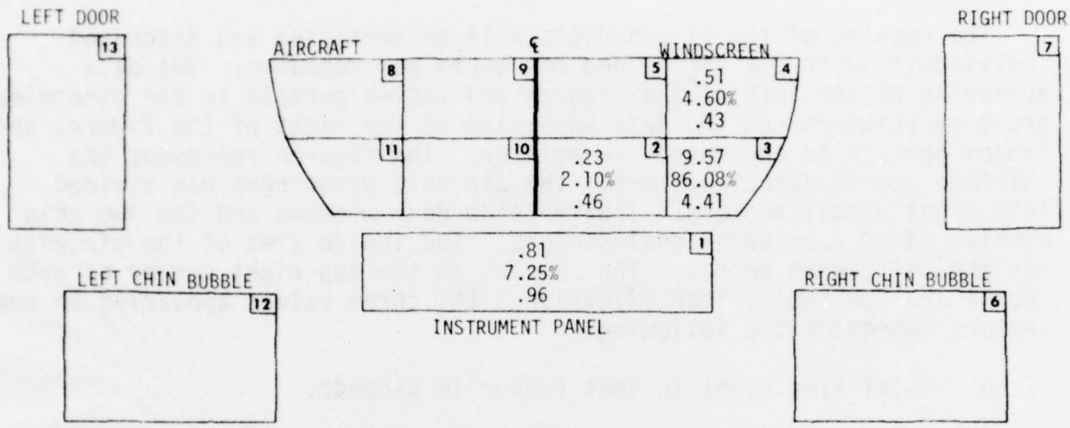
c. Mean visual dwell time for that sector. Dwell time was established by dividing the total time spent in the sector by the number of visual exits recorded for that sector.

The data presented in the tables are self-explanatory with the possible exception of the mean sector transitions/minute measure. This measure was derived by taking the total number of sector transitions made by each subject, dividing it by the time it took him to complete the maneuver, multiplying by 60, and then computing a mean.

Stabilized Hover. The first maneuver to be compared is the stabilized hover. The timing for this maneuver began with the pilot's first positive application of collective pitch pull and terminated with a stabilized three-foot hover.

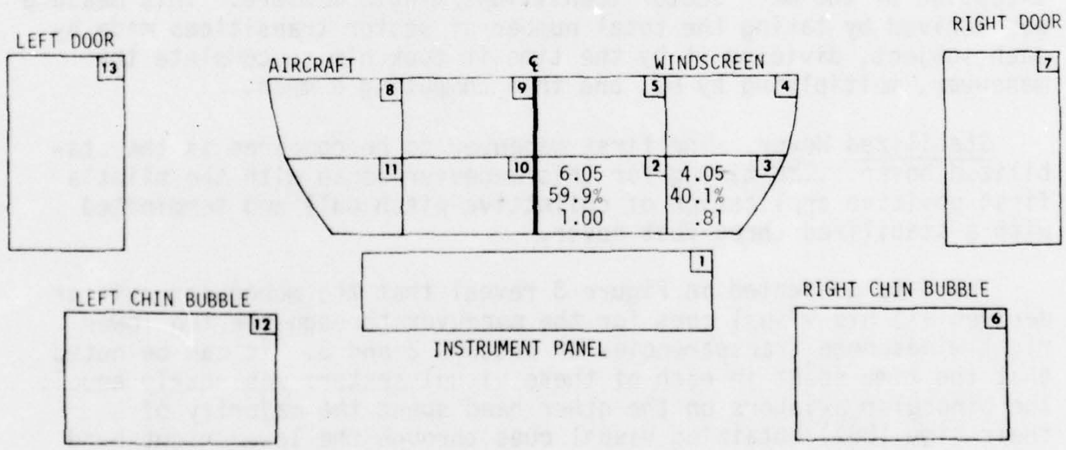
The data presented in Figure 3 reveal that the monocular aviator derived all his visual cues for the maneuver through the two lower right windscreen transparencies or sectors 2 and 3. It can be noted that the time spent in each of these visual sectors was nearly equal. The binocular aviators on the other hand spent the majority of their time (86%) obtaining visual cues through the lower right hand sector of the front windscreen or sector 3. They not only spent the perponderance of their time in this visual sector but also stayed there for increased periods as evidenced by the mean dwell time of 4.4 seconds. These data indicate that during this maneuver some binocular aviators looked into the cockpit which accounted for 7.3% of the total time and briefly scanned the upper right windscreen (sector 4) to obtain visual information (4.6% of time). The monocular aviator, as indicated earlier, used neither of the sectors to obtain visual information.

STABILIZED HOVER



BINOCULAR MEANS

STABILIZED HOVER



MONOCULAR VALUES

FIGURE 3. STABILIZED HOVER

Table 1 indicates that the monocular aviator completed this maneuver in a time which approximately equaled the mean time to complete for the binocular group. However, it can be seen from the sector transition data that he was more visually active than any of his binocular counterparts. It can also be seen from Table 1 that at least one binocular aviator used only one visual sector to obtain all necessary visual cues required to execute the maneuver. In all likelihood, this was probably visual sector 3.

Table 1

Stabilized Hover

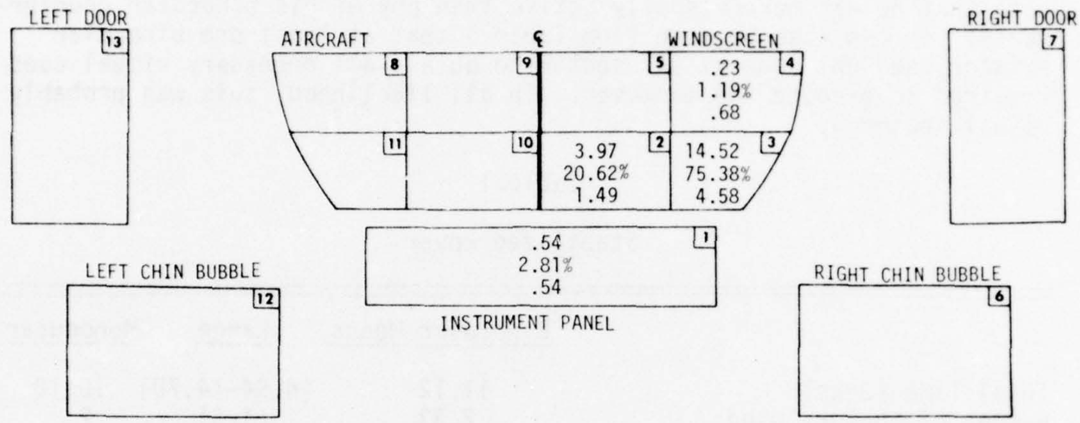
	Binocular Means	Range	Monocular
Total Time (Secs)	11.12	(4.94-14.70)	10.10
Number of Sectors Used	2.33	(1-3)	2
# of Sector Transitions (Permutations)	4.66	(0-9)	10
Mean Sector Transitions/Minute	27.76	(0-48.58)	59.4
Time Inside Aircraft (Secs)	.81	(0-3.52)	0
Time Outside Aircraft (Secs)	10.31	(4.23-14.09)	10.10

Forward Hover. The maneuver began from a stationary three-foot hover from which the subject pilot was instructed to hover forward for a distance of 60 feet and stop.

As can be seen in Figure 4, the binocular group spent only 2.8% of the total maneuver time inside the cockpit while the monocular aviator spent 15.2% of the total time inside. This was the only maneuver of the eleven recorded maneuvers in which the monocular aviator had a greater percentage of cockpit time than the binocular aviator. It can also be noted that there existed a more even distribution between sectors 1 and 2 for the monocular aviator and his dwell times were typically shorter.

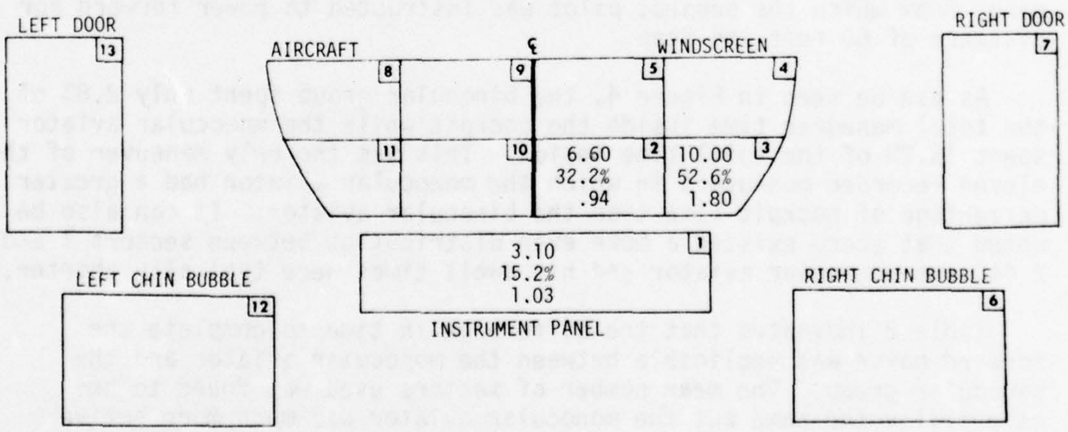
Table 2 indicates that the difference in time to complete the forward hover was negligible between the monocular aviator and the binocular group. The mean number of sectors used was found to be essentially the same but the monocular aviator was much more active (higher number of sector transitions) on the average than the binocular group with almost as many sector transitions as the most active binocular aviator. This is demonstrated by his 16 sector transitions (permutations) which better than doubled the mean of 7.17 transitions for the binocular group. The monocular aviator's high visual activity was again reflected in the mean sector transitions/minute data.

FORWARD HOVER



BINOCULAR MEANS

FORWARD HOVER



MONOCULAR VALUES

FIGURE 4. FORWARD HOVER

Table 2

Forward Hover

	Binocular Means	Range	Monocular
Total Time (Secs)	19.27	(9.20-29.0)	20.50
Number of Sectors Used	2.68	(2-3)	3
# of Sector Transitions (Permutations)	7.17	(1-17)	16
Mean Sector Transitions/Minute	21.57	(5.39-50.55)	46.83
Time Inside Aircraft (Secs)	.54	(0-1.32)	3.12
Time Outside Aircraft (Secs)	18.73	(9.17-29.60)	17.38

In summary, it may be fair to state that within the total visual areas of concern the monocular aviator, in general, used the same sectors of the windscreen as did the binocular aviators. However, he did not use the sectors the same percentage of time as the binocular group nor did he dwell there as long. As mentioned above, the monocular aviator spent more time in the cockpit than the binocular group and when looking inside, he stayed longer before going back to the windscreen than did the binocular aviators.

Rearward Hover. The rearward hover began from a stabilized three-foot hover from which the pilot hovered rearward for a distance of 60 feet and then stopped.

Figure 5 indicates for this maneuver the aviators spent a large percentage of time in sector 3 of the windscreen (binocular 73% and monocular 87%). The preference for obtaining visual cues from sector 3 is in keeping with the usage pattern found for the forward hover. Again as in the forward hover, the instrument panel was used, but on the average to a lesser extent by the monocular aviator. It can be seen that, with the exception of the instrument panel, virtually all visual information for all pilots was gained through sectors 2 and 3, as was the case for the forward hover and stabilized hover. Table 3 indicates that, in general, all aviators took longer to execute the rearward hover than they did the forward hover though the distance traveled was the same. For the binocular aviators, the average time increased by a factor of about 1.7 and the monocular aviator's time increased by a factor of about 2.4. With regard to visual activity, the monocular aviator did not vary to any great extent from the binocular group. However, when looking at the range data for this parameter, it is evident that he was a great deal more active than the least active of

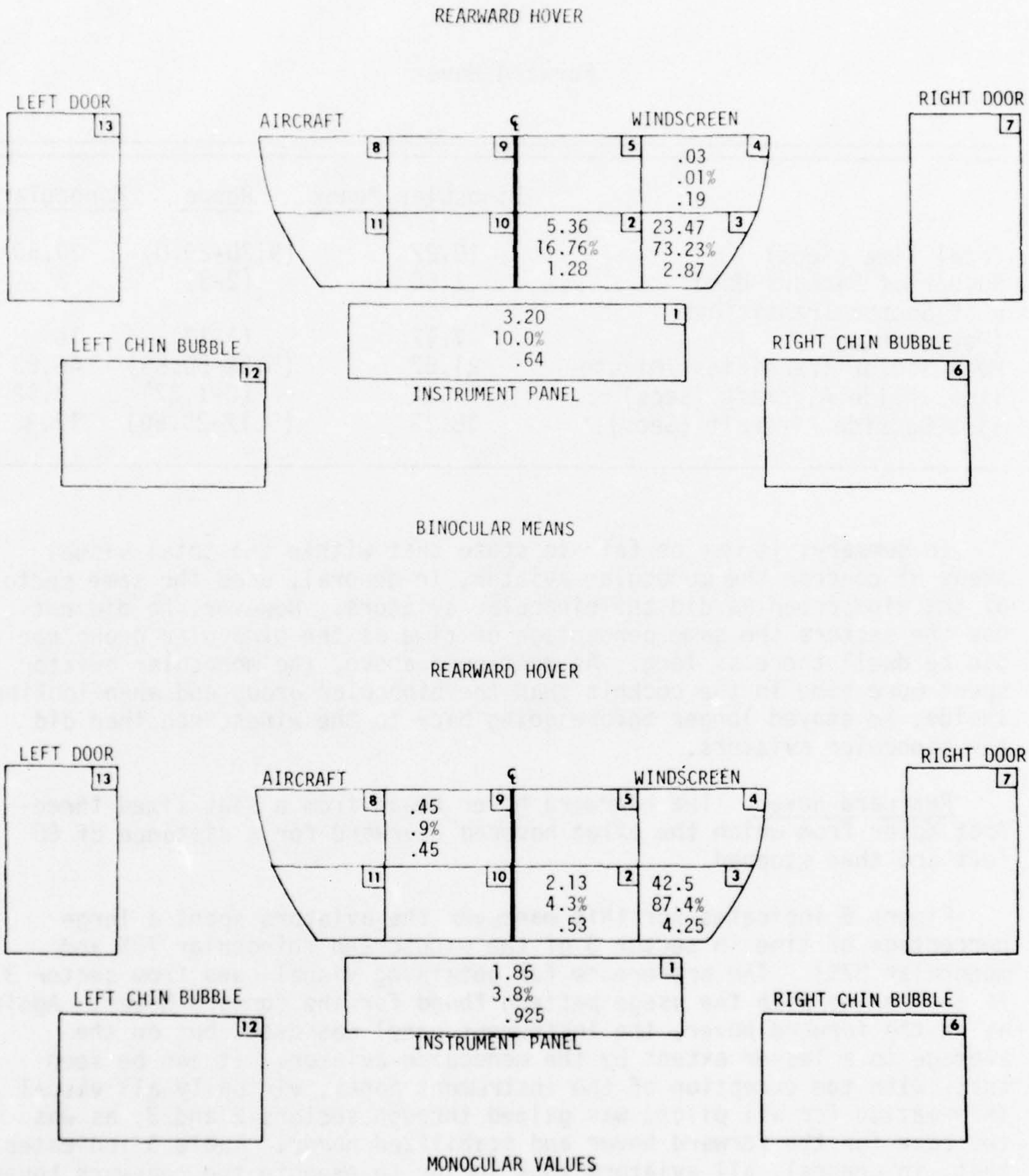


FIGURE 5. REARWARD HOVER

the binocular group. It can also be noted that the monocular aviator, though taking longer to complete the manever, did not in a like manner increase the amount of time spent inside the cockpit.

Table 3

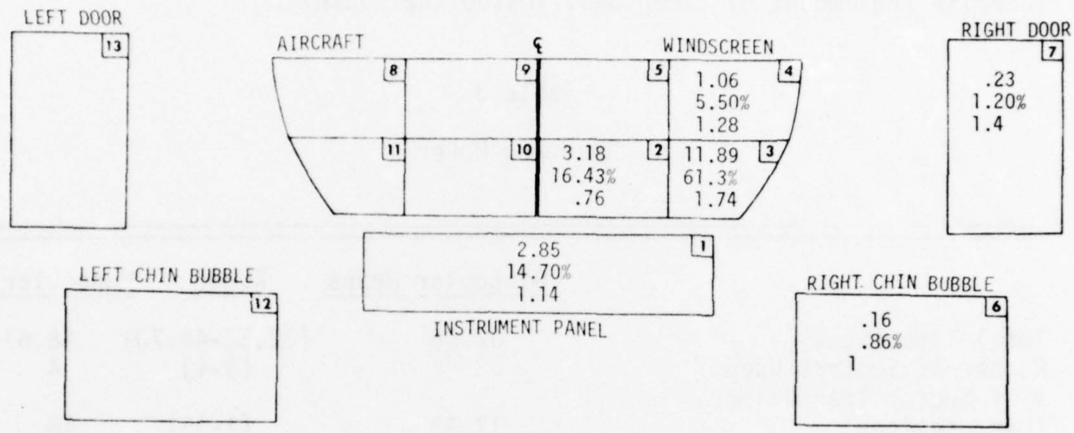
Rearward Hover

	Binocular Means	Range	Monocular
Total Time (Secs)	32.06	(22.52-44.70)	48.63
Number of Sectors Used	3	(3-4)	4
# of Sector Transitions (Permutations)	17.33	(1-35)	18
Mean Sector Transitions/Minute	29.68	(2.66-55.18)	22.20
Time Inside Aircraft (Secs)	3.13	(.26-6.05)	1.85
Time Outside Aircraft (Secs)	29.26	(22.27-41.74)	46.78

Hover Turn Left (90^{0}). This maneuver also started from a stabilized three-foot hover. The pilot was then instructed to turn left 90^{0} using the mast of the helicopter as a pivot point. The maneuver was considered accomplished once the pilot had completed a 90^{0} turn and stabilized the aircraft.

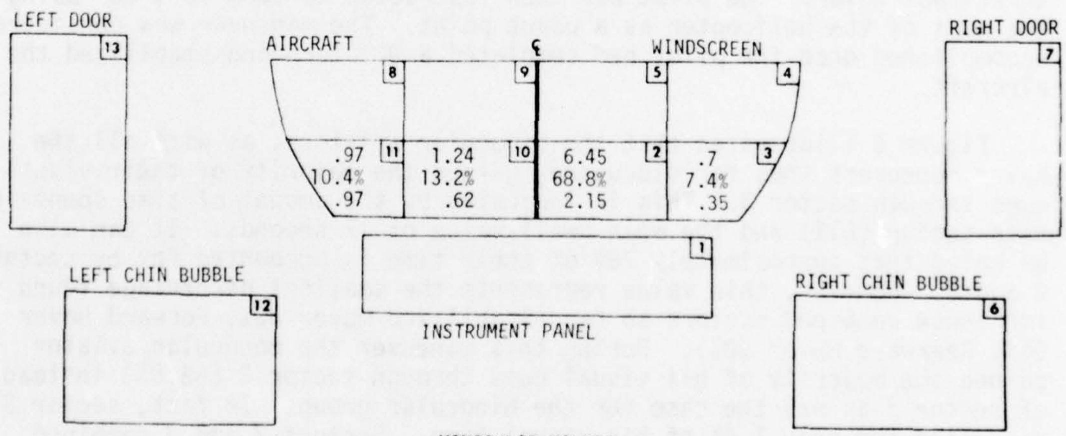
Figure 6 illustrates that the binocular aviators, as with all the hover maneuvers thus far discussed, gained the majority of their visual cues through sector 3. This is indicated by the amount of time spent in this sector (61%) and the mean dwell value of 17 seconds. It can also be noted that approximately 78% of their time is accounted for by sectors 2 and 3. However, this value represents the smallest percentage found for these combined sectors so far (Stabilized Hover 80%, Forward Hover 96%, Rearward Hover 90%). During this maneuver the monocular aviator gained the majority of his visual cues through sector 2 (68.8%) instead of sector 3 as was the case for the binocular group. In fact, sector 3 accounted for only 7.4% of his visual time. Sectors 2 and 3 combined for the monocular aviator accounted for 76% of his visual time which is nearly equal to that found for the binocular aviators. However, as with the binocular group this value for these combined sectors is lower than that found in the previous hover maneuvers (Stabilized Hover 100%, Forward Hover 85%, Rearward Hover 92%). It can also be noted from Figure 6 that the binocular aviators came inside the cockpit for an average of 14.7% of the time and at least one briefly used areas, 4, 6, and 7 which are all on the right side of the aircraft. The monocular aviator, on the other hand, did not come inside the aircraft during this maneuver and spent 24% of his time looking through sectors 10 and 11

HOVER TURN LEFT (90^{O})



BINOCULAR MEANS

HOVER TURN LEFT (90^{O})



MONOCULAR VALUES

FIGURE 6. HOVER TURN LEFT (90^{O})

located on the lower left side of the windscreen. It can be seen that he spent about an equal amount of time in these sectors. Since the direction of turn corresponded to the side of visual deficiency for the monocular aviator it is quite possible that these sectors were used to compensate for the visual loss. It is also possible that the binocular aviators were receiving necessary visual cues through the peripheral vision provided by their left eye and therefore did not need to go to these sectors directly.

Perhaps the most interesting data found in Table 4 involve time to complete the maneuver. It can be seen that the monocular aviator not only completed the maneuver more quickly than the average time for the binocular group but also the range data indicate he was faster than the fastest binocular pilot.

Table 4

Hover Turn Left (90^{o})

	Binocular Means	Range	Monocular
Total Time (Secs)	19.39	(16.92-22.00)	9.37
Number of Sectors Used	3.67	(3-5)	4
# of Sector Transitions (Permutations)	14.67	(2-26)	7
Mean Sector Transitions/Minute	45.39	(6.31-79.96)	44.82
Time Inside Aircraft (Secs)	2.85	(1.32-6.61)	0
Time Outside Aircraft (Secs)	16.54	(10.31-19.01)	9.37

Hover Sidewards Left. This maneuver started from a stationary three-foot hover and terminated after hovering to the left for a distance of 50 feet and stopping.

Figure 7 indicates that the monocular aviator for the first time, differs quite radically from the binocular aviators in terms of where he gains his visual cues. It can be seen that he spent all his time in the two visual sectors (11, 13) located at the far left of the aircraft. The percentage of time spent in these two sectors, the left door and lower portion of the windscreen, was nearly equal. This shift to a higher use of the visual transparencies on the left side of the aircraft to obtain visual information was seen in the 90^{o} hover turn left but not to this extent. Maneuver to the left, it must be remembered, represents movement in the direction of visual deficiency which provides an explanation for this shift.

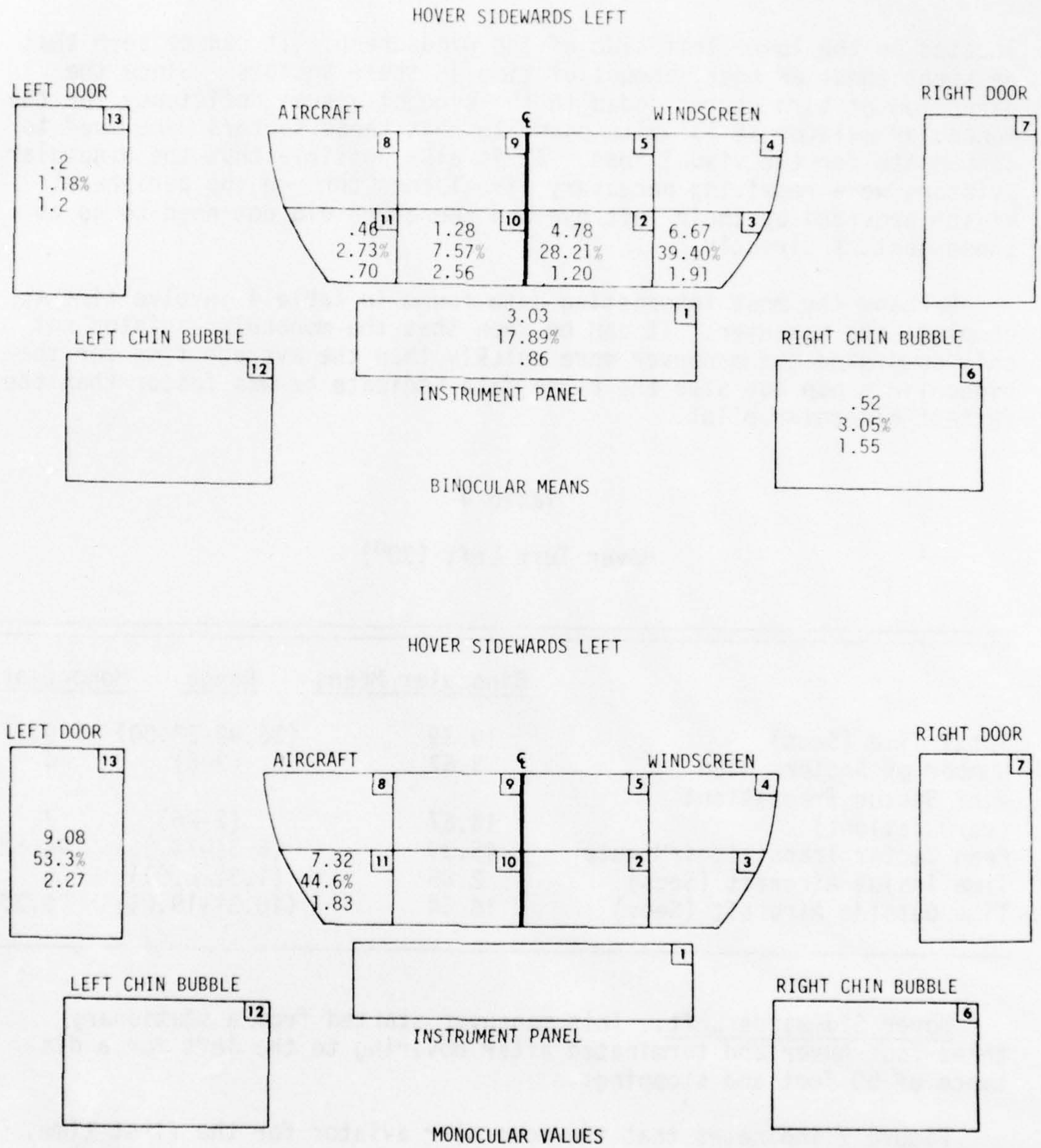


FIGURE 7. HOVER SIDEWARDS LEFT

It can be seen that the binocular aviators also exhibited an increased use of the left side of the aircraft but continued to gain the overwhelming amount of their outside visual cues from the two lower right hand sectors (2 and 3).

Though the distribution of visual sectors used was quite different, Table 5 indicates that in terms of time to complete the maneuver, sectors used, etc., the disparity in performance was not great.

Table 5

Hover Sidewards Left

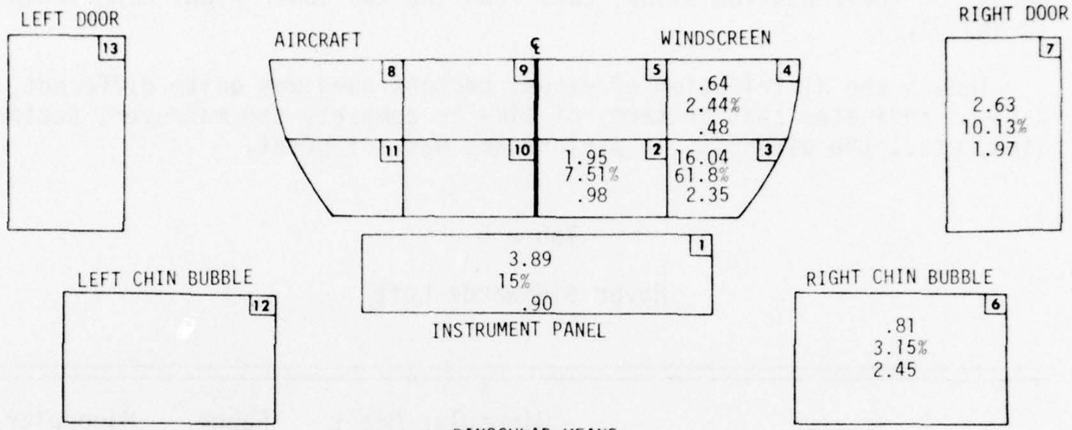
	Binocular Means	Range	Monocular
Total Time (Secs)	16.94	(8.80-23.77)	16.41
Number of Sectors Used	3.5	(2-5)	2
# of Sector Transitions (Permutations)	12.67	(6-18)	7
Mean Sector Transitions/Minute	48.51	(18.97-79.01)	25.59
Time Inside Aircraft (Secs)	3.03	.50-5.87)	0
Time Outside Aircraft (Secs)	13.91	(7.80-20.20)	16.41

Hover Sidewards Right. This maneuver was the same as the hover sidewards left except for the direction of movement.

Figure 8 indicates that there were, again, significant differences in oculomotor performance between the monocular and binocular aviators. The monocular aviator relied almost totally on visual cues obtained through the right door transparency. Not only did he spend over 96% of his time in this area, but also when there, stayed quite long as reflected in the average dwell time of some 12 seconds. The binocular aviators on the other hand, utilized sector 3 the largest percentage of the time (61.8%) and, in addition, spent an average of 15% of the time inside the cockpit. For the second time, it can be noted that at least one binocular aviator briefly used the right chin bubble.

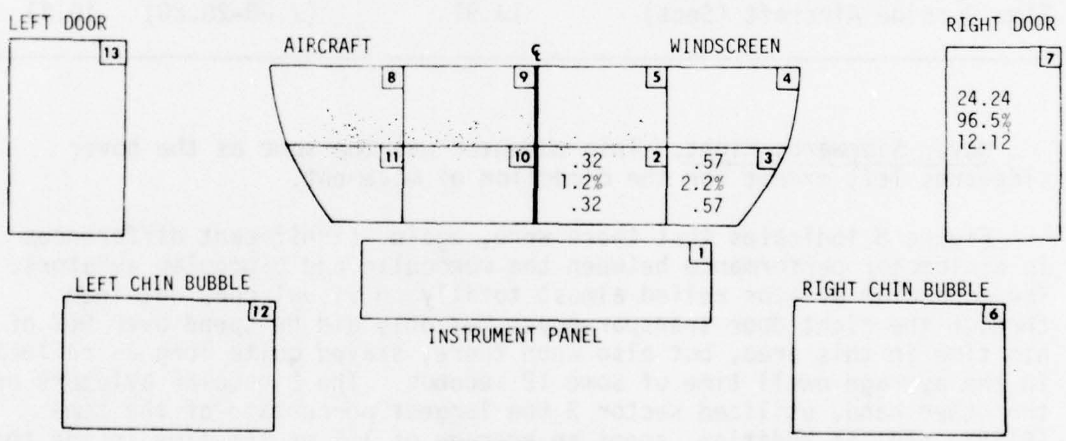
Table 6 indicates that the time to complete the maneuver was comparable. However, visual scan activity for the binocular group was considerably higher than for the monocular aviator.

HOVER SIDEWARDS RIGHT



BINOCULAR MEANS

HOVER SIDEWARDS RIGHT



MONOCULAR VALUES

FIGURE 8. HOVER SIDEWARDS RIGHT

Table 6

Hover Sidewards Right

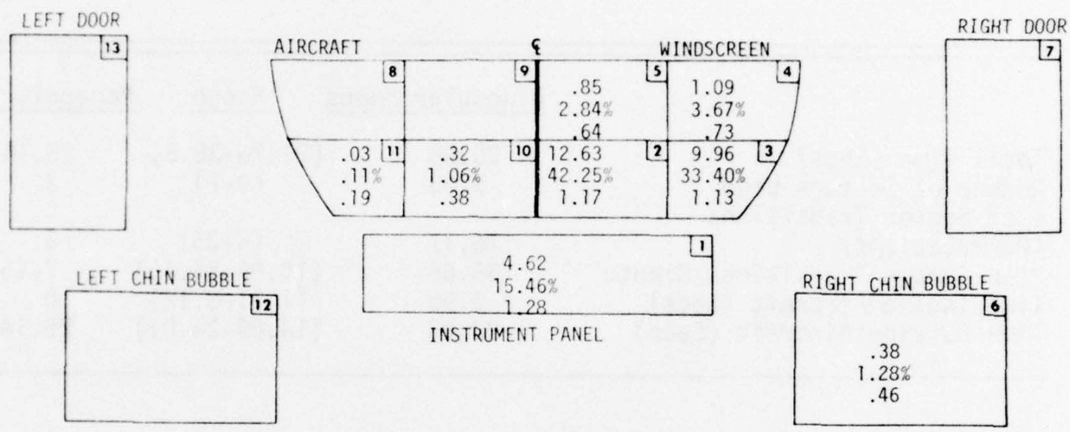
	Binocular Means	Range	Monocular
Total Time (Secs)	25.98	(21.76-38.5)	25.14
Number of Sectors Used	3.83	(2-7)	3
# of Sector Transitions (Permutations)	16.17	(6-35)	3
Mean Sector Transitions/Minute	35.86	(14.04-54.45)	7.16
Time Inside Aircraft (Secs)	3.90	(1.11-8.12)	0
Time Outside Aircraft (Secs)	22.08	(14.09-24.01)	25.14

Hover Turn Left (360^{o}). This maneuver began from a stabilized three-foot hover and terminated upon the completion of a 360^{o} left turn. The pivot point of rotation was the mast of the helicopter.

One would assume that the visual usage patterns for this maneuver might resemble those of the 90^{o} hover turn left. For the binocular group of aviators this was to some extent the case. Perhaps the most notable shift was found in sectors 2 and 3. During the 90^{o} maneuver, sector 3 was utilized 61% of the time and 2 got 16% utilization (Figure 9). Sector 3 and Sector 2 were utilized 33% and 42% of the time respectively. Another difference can be found in that sectors 6, 10, and 11 were used a small percentage of the time during this maneuver which was not the case for the 90^{o} turn. With regard to the monocular aviator, Figure 9 reveals that as with most of the other hover maneuvers requiring movement he did not come inside the cockpit. Also the time he spent looking out was heavily skewed toward sector 2 which accounted for some 90% of his time. It can be seen that during this turn he did not use sector 11, the far bottom left portion of the front windscreen, as he did on the 90^{o} turn left. During the 90^{o} turn he spent 10% of his time in sector 11.

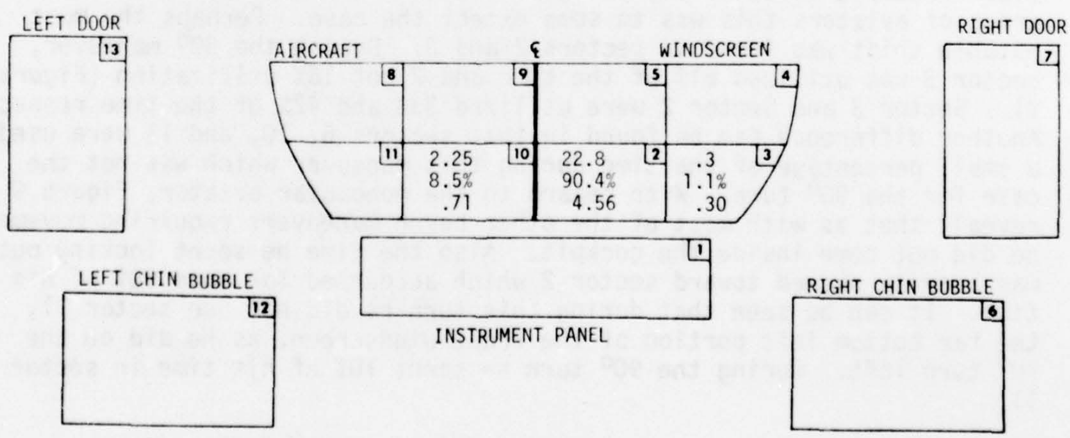
Table 7 indicates that the time taken by the monocular aviator to complete this maneuver was close to the mean time for the binocular group. It can also be noted that the monocular aviator was less visually active as evidenced by the number of sector transitions and the transition per minute data. This result is reflective of the large amount of time he spent in sector 2 combined with the long dwell time when in this sector.

HOVER TURN LEFT (360°)



BINOCULAR MEANS

HOVER TURN LEFT (360°)



MONOCULAR VALUES

FIGURE 9. HOVER TURN LEFT (360°)

Table 7

Hover Turn Left (360^o)

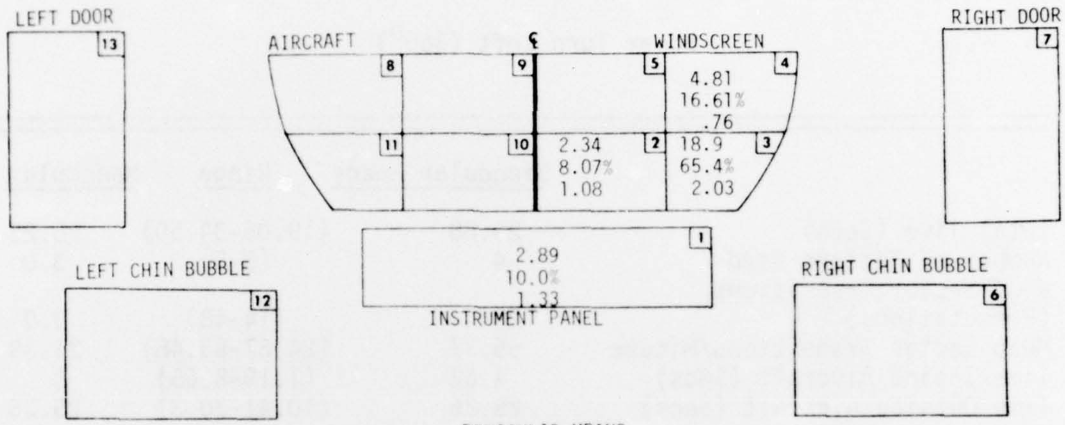
	Binocular Means	Range	Monocular
Total Time (Secs)	29.88	(19.06-34.50)	25.25
Number of Sectors Used	4	(3-5)	3.0
# of Sector Transitions (Permutations)	28	(14-48)	9.0
Mean Sector Transitions/Minute	56.37	(24.67-83.48)	21.39
Time Inside Aircraft (Secs)	4.62	(1.19-8.65)	0
Time Outside Aircraft (Secs)	25.26	(10.41-30.3)	25.25

Hover Turn Right (360^o). This maneuver was the same as the 360^o hover turn left except for the direction of turn.

It can be seen in Figure 10 that outside cockpit visual performance during this maneuver was quite similar for both monocular and binocular aviators. Opposed to the 360^o left turn the aviators shifted to the right to obtain their visual cues. This shift is demonstrated by the increased amount of time spent looking through sectors 3 and 4. This is also the first maneuver thus far encountered in which the upper right portion of the windscreen (sector 4) has been used to any appreciable extent. The most notable differences between the monocular and binocular aviators is the fact that the monocular pilot did not come inside the cockpit nor did he use the right door transparency (sector 7). Not coming inside the cockpit for visual information is in keeping with his past visual performance in executing most hover maneuvers which required movement.

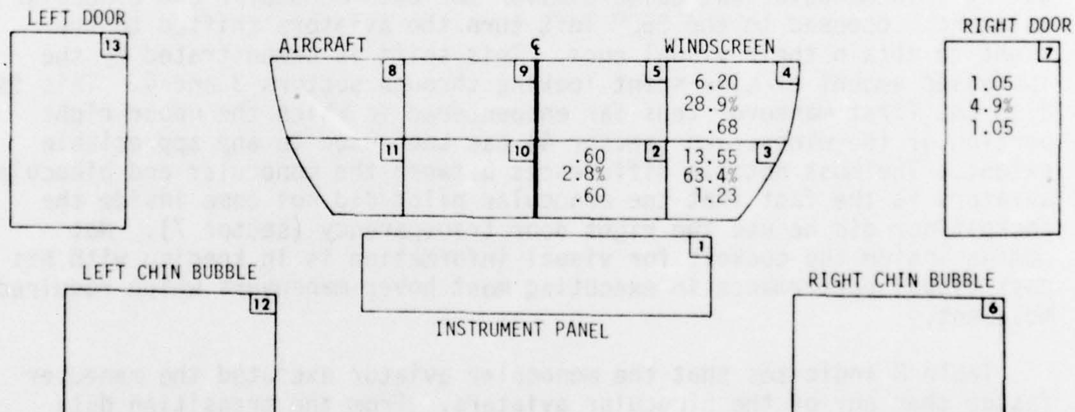
Table 8 indicates that the monocular aviator executed the maneuver faster than any of the binocular aviators. From the transition data presented in Table 8 it can also be seen that when compared to the average for the binocular aviators the monocular aviator was a bit more visually active.

HOVER TURN RIGHT (360^o)



BINOCULAR MEANS

HOVER TURN RIGHT (360^o)



MONOCULAR VALUES

FIGURE 10. HOVER TURN RIGHT (360^o)

Table 8

Hover Turn Right (360^{o})

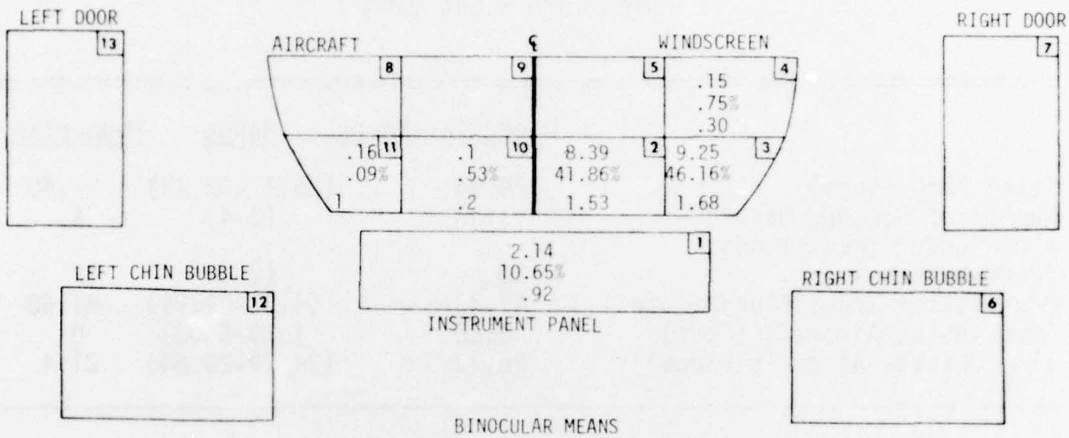
	Binocular Means	Range	Monocular
Total Time (Secs)	28.98	(26.17-32.23)	21.40
Number of Sectors Used	3.33	(2-4)	4
# of Sector Transitions (Permutations)	20	(2-40)	22
Mean Sector Transition/Minute	41.83	(4.53-91.71)	61.68
Time Inside Aircraft (Secs)	2.85	(.16-5.00)	0
Time Outside Aircraft (Secs)	26.13	(24.79-29.84)	21.4

Hover Turn Right (90^{o}). The 90^{o} hover turn to the right started from a stationary three-foot hover and was completed after the pilot, using the mast as a pivot point, had rotated the aircraft 90^{o} to the right.

Figure 11 shows that during this maneuver the binocular aviators spent essentially all their outside time looking through sectors 2 and 3. Also it can be noted that the amount of time spent in each was quite similar (41.9% and 46.2%). The monocular aviator, on the other hand, used mostly sector 3 (85.6%), while using sector 2 only 8% of the time. As opposed to the 360^{o} hover turn right, the binocular aviators virtually eliminated the use of sector 4 (upper right windscreen) and the monocular aviator showed a marked reduction in the use of this sector. As in the past, with the exception of the rearward and forward hover, the monocular aviator did not come into the cockpit for visual information.

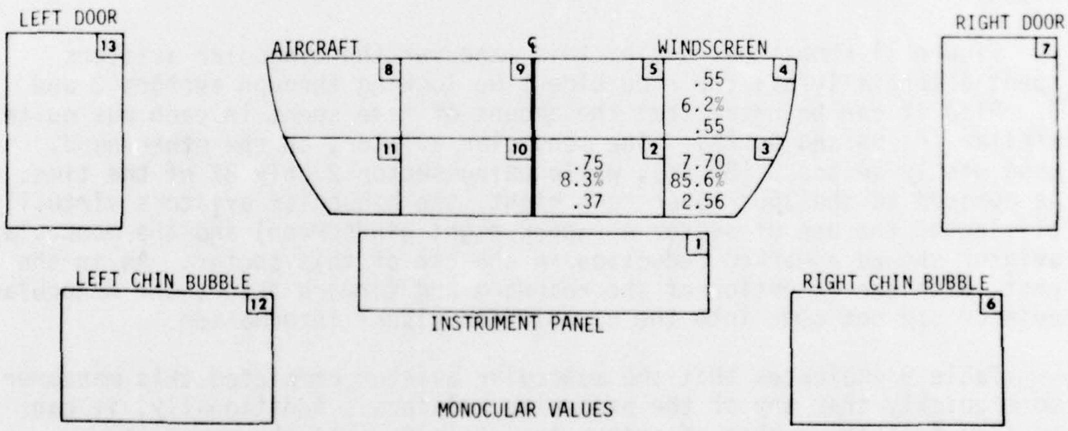
Table 9 indicates that the monocular aviator completed this maneuver more quickly than any of the binocular aviators. Additionally, it can be seen from the number of sector transitions, that the monocular aviator made fewer transitions than any of the binocular aviators.

HOVER TURN RIGHT (90^o)



BINOCULAR MEANS

HOVER TURN RIGHT (90^o)



MONOCULAR VALUES

FIGURE 11. HOVER TURN RIGHT (90^o)

Table 9

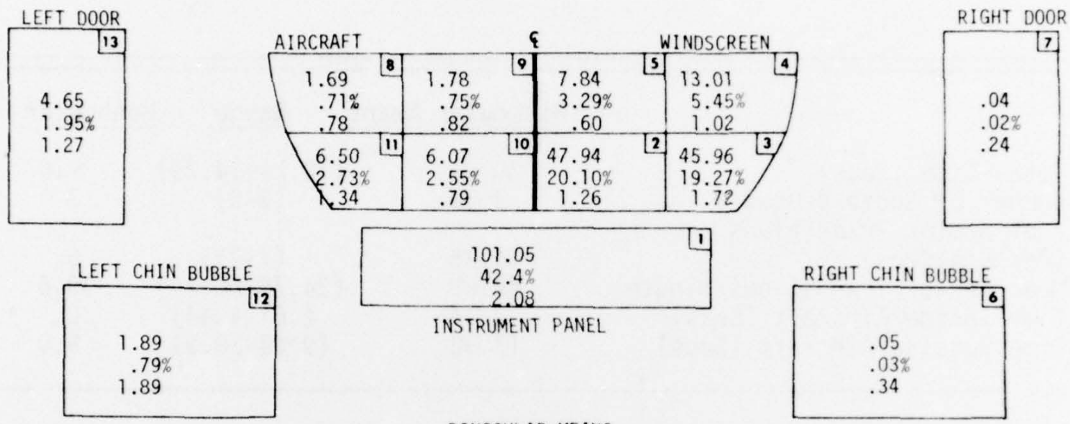
Hover Turn Right (90^{o})

	Binocular Means	Range	Monocular
Total Time (Secs)	20.06	(10.71-34.39)	9.0
Number of Sectors Used	3.50	(3-5)	3
# of Sector Transitions (Permutations)	14.33	(7-21)	6
Mean Sector Transitions/Minute	42.88	(24.78-66.74)	39.6
Time Inside Aircraft (Secs)	2.14	(.61-4.44)	0
Time Outside Aircraft (Secs)	17.92	(9.58-30.91	9.0

Normal Traffic Pattern - Take Off to Hover Terminate - Left Traffic. This maneuver began with a normal take off from the ground, proceeded through a normal left traffic pattern, a normal approach and terminated in a three-foot hover.

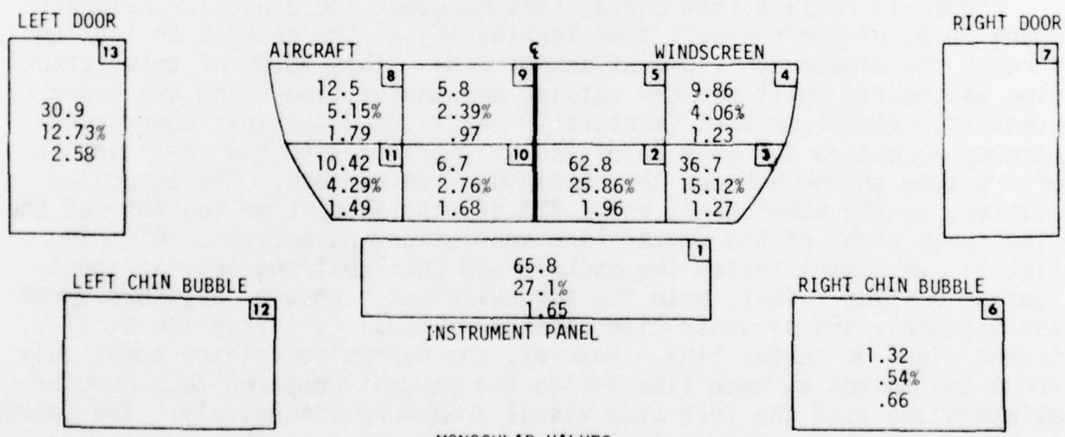
Figure 12 reveals that during this maneuver the binocular aviators spent 90.5% of their visual time looking inside the cockpit or looking through the windscreen right of center line. This 90.5% of total visual time was nearly split between outside and inside time. The two lower windscreen visual sectors (sectors 10 and 11) and the left door transparency accounted for only 7% of the visual time with the remaining 3% of the time shared between the remaining five sectors. The monocular aviator, on the other hand, spent 72% of his visual time looking out the windscreen right of the center line and inside the cockpit. Of this time 27% was spent inside the cockpit and the remaining 45% was spent looking outside. Thus, both the monocular and binocular aviators spent approximately 45% of their time obtaining visual cues from the windscreen right of center line. However, the monocular aviator spent only about two-thirds as much time inside the cockpit compared to binocular aviators and used the left side visual area more extensively. The tendency to use the left transparencies to a greater extent is most pronounced when comparing the binocular usage of only 1.95% to the monocular usage of 12.7%. This increased use of the left by the monocular aviator was quite likely precipitated by the fact that all turns were left and therefore in the direction of his visual deficiency. This situation would require more head rotation to the left to gain necessary clearing information.

NORMAL TRAFFIC PATTERN
TAKE OFF TO HOVER TERMINATE - LEFT TRAFFIC



BINOCULAR MEANS

NORMAL TRAFFIC PATTERN
TAKE OFF TO HOVER TERMINATE - LEFT TRAFFIC



MONOCULAR VALUES

FIGURE 12. NORMAL TRAFFIC PATTERN - TAKE OFF TO HOVER TERMINATE - LEFT TRAFFIC

Table 10 indicates that the difference between the average time for the binocular aviators to complete the maneuver and the monocular aviator was on the order of only four seconds. With regard to the number of visual sectors used it can be seen that the monocular aviator used as many as did the binocular aviator with the highest number. The transition data indicate that the monocular aviator's performance was similar to the average for the binocular group.

Table 10

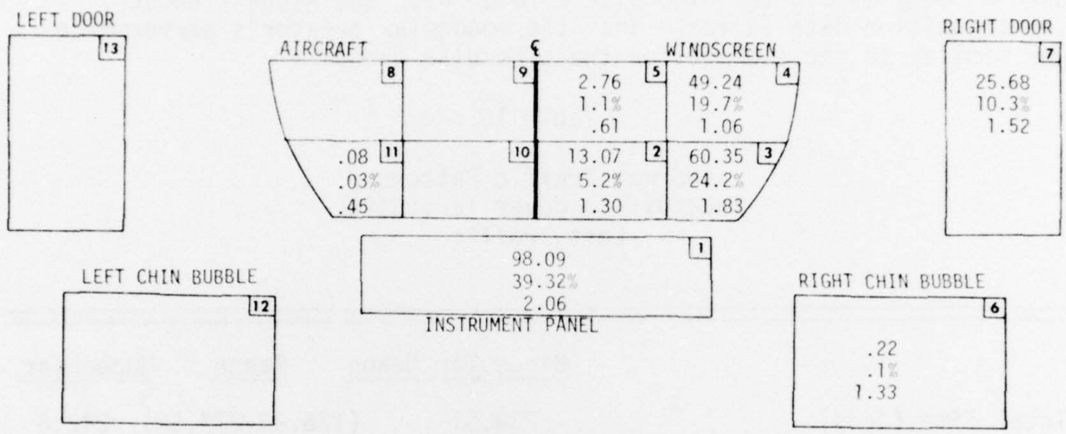
Normal Traffic Pattern
Take Off to Hover Terminate
Left Traffic

	Binocular Means	Range	Monocular
Total Time (Secs)	238.51	(176.83-277.50)	242.8
Number of Sectors Used	5.96	(4-10)	10
# of Sector Transitions (Permutations)	159.67	(127-187)	147
Mean Sector Transitions/Minute	38.08	(36.98-55.05)	39.42
Time Inside Aircraft (Secs)	101.05	(57.87-152.43)	65.8
Time Outside Aircraft (Secs)	137.46	(118.96-160.13)	177.0

Normal Traffic Pattern - Take Off to Touchdown - Right Traffic. This maneuver started with a normal take off from the ground, proceeded through a normal right traffic pattern, a normal approach, and terminated with aircraft touchdown.

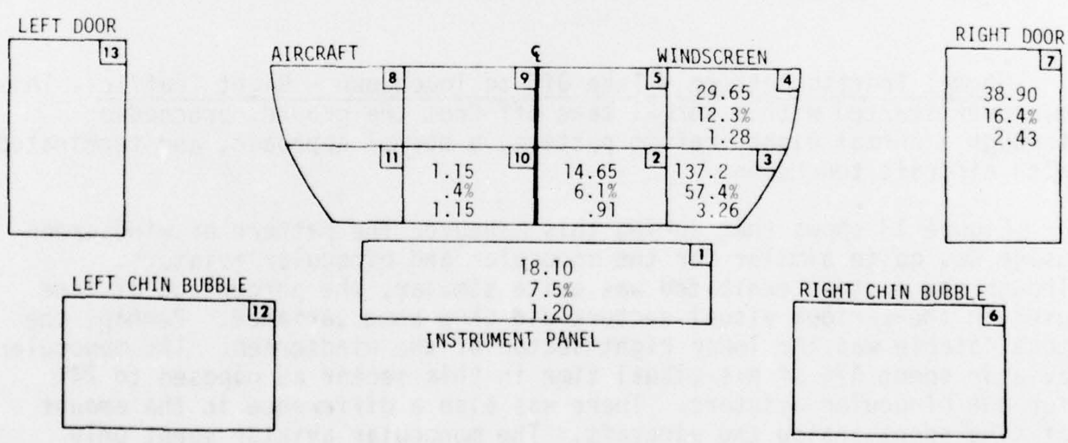
Figure 13 shows that during this maneuver the pattern of windscreen usage was quite similar for the monocular and binocular aviators. Though the pattern exhibited was quite similar, the percentage of time used in the various visual sectors did show some variance. Perhaps the most notable was the lower right sector of the windscreen. The monocular aviator spent 57% of his visual time in this sector as opposed to 24% for the binocular aviators. There was also a difference in the amount of time spent inside the aircraft. The monocular aviator spent only 7.5% inside while the binocular aviators spent some 39% of their total time inside the aircraft. The visual pattern as a whole, when compared to the left traffic pattern, shows a shift to the right as would be expected.

NORMAL TRAFFIC PATTERN
TAKE OFF TO TOUCHDOWN - RIGHT TRAFFIC



BINOCULAR MEANS

NORMAL TRAFFIC PATTERN
TAKE OFF TO TOUCHDOWN - RIGHT TRAFFIC



MONOCULAR VALUES

FIGURE 13. NORMAL TRAFFIC PATTERN - TAKE OFF TO TOUCHDOWN - RIGHT TRAFFIC

Table 11 indicates there was little difference between the time for the monocular aviator to complete the maneuver and the average time for the binocular group. Though the monocular aviator used more visual sectors than any of the binocular aviators as evidenced by the sectors utilized data, he also was a bit less visually active as can be seen in the sector transition data.

Table 11

Normal Traffic Pattern
Take Off to Touchdown
Right Traffic

	Binocular Means	Range	Monocular
Total Time (Secs)	249.50	(198.4-284.7)	239.65
Number of Sectors Used	4.73	(4-5)	6
# of Sector Transitions (Permutations)	158.33	(119-174)	110
Mean Sector Transitions/Minute	38.03	(28.74-55.75)	27.54
Time Inside Aircraft (Secs)	98.10	(50.11-139.06)	18.10
Time Outside Aircraft (Secs)	151.41	(139.45-171.19)	221.55

CONCLUSIONS

The data gathered in this investigation are interesting from several viewpoints. First, the very fact that this monocular aviator as well as other monocular aviators can, after training, perform with proficiency all required maneuvers is evidence that monocular cues are sufficient to provide acceptable helicopter control. This fact alone is of particular importance when one considers that many proposed and/or developmental systems for meeting 24-hour operational capability will in essence present aviators with monocular type visual cues. That is to say, these image sensor/display systems will be void of retinal disparity and convergence cues. As with the monocular aviator there is no fundamental reason why the loss of these cues must necessarily preclude effective pilot performance. Additionally, if one thinks of the monocular aviator

as representing a finite field-of-view (FOV) monocular sensor with unaided eyeball capability, his usage of the visual areas might provide some information concerning image sensor orientation and desirable FOV requirements for fixed sensors. Admittedly such information based on the sample of only one must be tentative. Also, it must be remembered that all oculomotor performance data in this study are based on the visual envelope provided in the UH-1 and do not necessarily represent what a pilot might want or use with a different visual envelope. However, if the monocular aviator data are considered in the sensor context mentioned above, it would be most interesting to consider how well an aviator could perform sideward hovering flight with a fixed forward sensor with some fairly limited FOV. Based on this aviator's data, one might predict that performance might be less than desirable. It was evident that during such maneuvers the monocular aviator, for the most part, used either the far right or left visual sectors, depending upon his directional movement, to obtain the visual cues necessary for flight control. Some shift to the left toward his visual deficiency when moving left would be expected since the central as well as peripheral vision normally provided by the eye was not there. However, the extent of this shift would not be predicted from viewing the binocular data. By the same token, the dramatic shift to the right when moving right would not have been evident if one viewed only the binocular data. Consequently, for adequate hover sideward performance to be realized, it may be necessary to rotate an image sensor toward the direction of movement.

The monocular data also, in some instances, indicated a higher visual activity even though the delineation of the visual sectors was very gross. This may indicate that monocular viewing combined with something less than a binocular FOV, will, if adequate cues are to be obtained, require an increase in visual scan. It was also evident that this visual capability was associated with less time inside the cockpit. Whether this was necessary because more time was needed outside the cockpit is unknown. However, if this is the case it can then be inferred that if a pilot is using a monocular system with a reduced FOV he will spend more time outside the cockpit. This situation might then require a clear cut division of duties with a copilot to insure adequate instrument monitoring.

The data also indicated that during the various maneuvers the chin bubbles were used infrequently and therefore cannot be considered as visual rich areas from a central vision consideration. However, this conclusion must be attenuated by the results of an earlier investigation[7] dealing with slope operations in which the usage of the chin bubbles was found to be as high as 14%. The upper portions of the windscreen either side of the center line (sectors 5 and 9) were seldom used and represented a small percent of outside time. Thus it might be concluded that independent of the seat used by the pilot these areas are not rich in visual cues. On the other hand, all aviators obtained much

visual information through the corner right portions (sectors 2 and 3) of the windscreen. For the binocular aviators the lowest percentage of the outside time accounted for by these combined sectors was 49%. This percentage went to nearly 100% for the rearward hover. For the monocular aviator, with the exception of the sideward hovers in which these sectors were not used, the percentage of outside time for these sectors ranged from 44% (Normal Traffic Pattern Left) to 100% (Stabilized Hover). The implication of this finding would seem to be, with the exceptions noted, that the visual rich areas for helicopter control for the maneuvers considered exists to a large degree in the lower right portions of the windscreen. This, of course, is true when flying from the right but the reverse should be expected to hold if seated on the left. This finding does not address the peripheral cue requirements, but does indicate that any sensor should cover these areas.

When comparing the data of the monocular aviator with that of the binocular aviators, it can be seen that, in general, they used the same sectors. However, the total percentage of time they spent in these sectors was often different and so were the dwell times. The most dramatic differences in visual performance appeared when aircraft movement was in the direction of the monocular aviator's visual deficiency and in terms of the time spent inside the cockpit.

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U. S. Army Aeromedical Research Laboratory, Ft. Rucker, AL
Comparison of Oculomotor Performance of Monocular and Binocular Aviators During VFR Helicopter Flight,
Mark A. Hofmann, Thomas L. Frezell, 37 pp., Aviation Psychology Division, March 1977.

UNCLASSIFIED
1. Eye Movement Recording
2. Visual Workload
3. Pilot Performance
4. Helicopter Visual Data
5. Rotary Wing Aircraft

This investigation provides data concerning the visual performance of six binocular Army aviators and one monocular Army aviator during eleven flight maneuvers. All maneuvers were performed in a JUH-1H helicopter and visual data were acquired by means of a corneal reflection technique. Data were recorded on video tape and 16mm film. Thirteen visual areas were used to include: eight windscreen sectors; two side windows and chin bubbles; and an inside cockpit sector. Data presented include percentage of time spent in each sector, average dwell time per sector and sector transition (permutation) values. In addition to the objective data, a discussion of the retraining period for the monocular aviator is provided. The data revealed that, in general, both the monocular aviator and binocular aviators used the same visual sectors. However, the total percentage of time they spent in these sectors were often different and so were the dwell times. The most dramatic differences in visual performance appeared when aircraft movement was in the direction of the monocular aviator's visual deficiency and in terms of the time spent inside the cockpit. The monocular aviator was found to perform all maneuvers in a most acceptable manner.

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U. S. Army Aeromedical Research Laboratory, Ft. Rucker, AL
Comparison of Oculomotor Performance of Monocular and Binocular Aviators During VFR Helicopter Flight,
Mark A. Hofmann, Thomas L. Frezell, 37 pp., Aviation Psychology Division, March 1977.

UNCLASSIFIED
1. Eye Movement Recording
2. Visual Workload
3. Pilot Performance
4. Helicopter Visual Data
5. Rotary Wing Aircraft

This investigation provides data concerning the visual performance of six binocular Army aviators and one monocular Army aviator during eleven flight maneuvers. All maneuvers were performed in a JUH-1H helicopter and visual data were acquired by means of a corneal reflection technique. Data were recorded on video tape and 16mm film. Thirteen visual areas were used to include: eight windscreen sectors; two side windows and chin bubbles; and an inside cockpit sector. Data presented include percentage of time spent in each sector, average dwell time per sector and sector transition (permutation) values. In addition to the objective data, a discussion of the retraining period for the monocular aviator is provided. The data revealed that, in general, both the monocular aviator and binocular aviators used the same visual sectors. However, the total percentage of time they spent in these sectors were often different and so were the dwell times. The most dramatic differences in visual performance appeared when aircraft movement was in the direction of the monocular aviator's visual deficiency and in terms of the time spent inside the cockpit. The monocular aviator was found to perform all maneuvers in a most acceptable manner.

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